Appendix A

Emission Factor Derivations

The following physical constants and standard conditions were utilized to derive the criteria-pollutant emission factors used to calculate criteria pollutant and toxic air contaminant emissions.

standard temperature[a]:	70^oF
standard pressure[a]:	14.7 psia
molar volume:	385.3 dscf/ lbmol
ambient oxygen concentration:	20.95%
dry flue gas factor[b]:	8600 dscf/MM BTU
natural gas higher heating value:	1030 BTU/dscf

[a]BAAQMD standard conditions per Regulation 1, Section 228.

[b]F-factor is based upon the assumption of complete stoichiometric combustion of natural gas. In effect, it is assumed that all excess air present before combustion is emitted in the exhaust gas stream. Value shown reflects the typical composition and heat content of utility-grade natural gas in San Francisco bay area.

Table A-1 summarizes the regulated air pollutant emission factors that were used to calculate mass emission rates for each source. All units are pounds per million BTU of natural gas fired based upon the high heating value (HHV). All emission factors are after abatement by applicable control equipment.

Table A-1
Controlled Regulated Air Pollutant Emission Factors for Gas Turbines and HRSGs

Pollutant	Source			
	Gas Turbine		Gas Turbine & HRSG Combined	
	lb/MM BTU	lb/hr	lb/MM BTU	lb/hr
Nitrogen Oxides (as NO_2)	0.00904[a]	18	0.00904[a]	19.2
Carbon Monoxide	0.0132[b]	26.3	0.0132[b]	28.07
Precursor Organic Compounds	0.00126[c]	2.51	0.00126[c]	2.68
Particulate Matter (PM_{10})	0.00452	9	0.00565	12
Sulfur Dioxide	0.0006	1.2	0.0006	1.28

[a]based upon the permit condition emission limit of 2.5 ppmvd NO_x @ 15% O_2 that reflects the use of dry low-NO_x combustors at the CTG, low-NO_x burners at the HRSG, and abatement by the proposed A-1 and A-2 Selective Catalytic Reduction Systems with ammonia injection

[b]based upon the permit condition emission limit of 6 ppmvd CO @ 15% O_2

[c]based upon BACT specification of 1 ppmvd @ 15% O_2

Regulated Air Pollutants

NITROGEN OXIDE EMISSION FACTORS

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

The combined NO_x emissions from the CTG and HRSG will be limited to 2.5 ppmv, dry @ 15% O_2. This emission limit will also apply when the HRSG duct burners are in operation. This concentration is converted to a mass emission factor as follows:

(2.5 ppmvd)(20.95 - 0)/(20.95 - 15) = 8.8 ppmv NO_x, dry @ 0% O_2

($8.8/10^6$)(1 lbmol/385.3 dscf)(46.01 lb NO_2/lbmol)(8600 dscf/MM BTU)

= **0.00904 lb NO_2/MM BTU**

The NO_x mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

(0.00904 lb/MM BTU)(1,990.5 MM BTU/hr) = **18 lb NO_x/hr**

The NO_x mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the gas turbine and HRSG and is calculated as follows:

(0.00904 lb/MM BTU)(2,124 MM BTU/hr) = **19.2 lb NO_x/hr**

CARBON MONOXIDE EMISSION FACTORS

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

The combined CO emissions from the CTG and HRSG duct burner will be conditioned to a maximum controlled CO emission limit of 6 ppmv, dry @ 15% O_2 during all operating modes except gas turbine start-up and shutdown. The emission factor corresponding to this emission concentration is calculated as follows:

(6 ppmv)(20.95 - 0)/(20.95 - 15) = 21.13 ppmv, dry @ 0% O_2

($21.13/10^6$)(lbmol/385.3 dscf)(28 lb CO/lbmol)(8600 dscf/MM BTU)

= **0.0132 lb CO/MM BTU**

The CO mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

(0.0132 lb/MM BTU)(1,990.5 MM BTU/hr) = **26.3 lb CO/hr**

The CO mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the CTG and HRSG and is calculated as follows:

(0.0132 lb/MM BTU)(2,124 MM BTU/hr) = **28.04 lb CO/hr**

The applicant has calculated and utilized a slightly higher mass emission rate of **28.07 lb CO/hr**.

PRECURSOR ORGANIC COMPOUND (POC) EMISSION FACTORS

Combustion Gas Turbine

In response to EPA concerns, the applicant has agreed to a maximum POC (non-methane, non-ethane hydrocarbon) emission rate of 1 ppmvd @ 15% O_2 for all gas turbine operating modes and conditions, except gas turbine start-up and shutdown.

(1 ppmvd @ 15% O_2)(20.95 – 0)/(20.95 – 15) = 3.52 ppmvd @ 0% O_2

(3.52 ppmvd @ 0% O_2)[(16 lb CH_4/lb-mol)(8600 dscf/MM BTU)]/[(10^6)(385.3 dscf/lbmol)]

= 0.00126 lb POC/MM BTU

This converts to a mass emission rate as follows:

(0.00126 lb POC/MM BTU)(1990.5 MM BTU/hr) = **2.51 lb POC/hr**

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

In response to EPA concerns, the applicant has agreed to a maximum POC (non-methane, non-ethane hydrocarbon) emission rate of 1 ppmvd @ 15% O_2 for all gas turbine operating modes and conditions, including HRSG duct burner firing, except gas turbine start-up and shutdown.

The mass emission rate when the HRSG duct burners are in operation is as follows:

(0.00126 lb POC/MM BTU)(2,124 MM BTU/hr) = **2.7 lb POC/hr**

PARTICULATE MATTER (PM_{10}) EMISSION FACTORS

Combustion Gas Turbine

Based upon the results of a source test of a Westinghouse 501F gas turbine (without duct burners) operated by Calpine in Pasadena, Texas, the applicant has proposed a reduced PM_{10} emission rate of 9 lb/hr for full load operation of the gas turbine alone. The source test was conducted in accordance with EPA Method 5 and employed both front and back half (filterable and condensable) particulate collection methods. Based upon three test runs, the average PM_{10} emission rate was 5.4 lb/hr. The corresponding PM_{10} emission factor is therefore:

(9 lb PM_{10}/hr)/(1,990.5 MM BTU/hr) = **0.00452 lb PM_{10}/MM BTU**

The following stack data will be used to calculate the grain loading at standard conditions for full load gas turbine operation without duct burner firing to determine compliance with BAAQMD Regulation 6-310.3.

PM_{10} mass emission rate:	9 lb/hr
flow rate:	953,965 acfm @ 12.24% O_2 and 170^oF
moisture content:	10.17% by volume

Converting flow rate to standard conditions:

(953,965 acfm)(70 + 460 ^oR/170 + 460 ^oR)(1 – 0.1017) = 720,923 dscfm

Converting to grains/dscf:

(9 lb PM_{10}/hr)(1 hr/60 min)(7000 gr/lb)/(720,923 dscfm) = 0.00146 gr/dscf

Converting to 6% O_2 basis:

(0.00146 gr/dscf)[(20.95 - 6)/(20.95 – 12.24)] = 0.0025 gr/dscf @ 6% O_2

Combustion Gas Turbine and HRSG Combined

The PM_{10} emission factor is based upon the Westinghouse vendor guarantee of 12 lb/hr at the maximum combined firing rate of 2,124 MM BTU/hr during duct burner firing and steam injection power augmentation. The corresponding PM_{10} emission factor is therefore:

(12 lb PM_{10}/hr)/(2,124 MM BTU/hr) = **0.00565 lb PM_{10}/MM BTU**

It is assumed that this PM_{10} emission factor includes secondary PM_{10} formation of particulate sulfates.

The following stack data will be used to calculate the grain loading for simultaneous CTG and HRSG operation at standard conditions to determine compliance with BAAQMD Regulation 6-310.3.

PM_{10} mass emission rate:	12 lb/hr
typical flow rate:	956,141 acfm @ 10.28% O_2 and 170^oF
typical moisture content:	15.03% by volume

Converting flow rate to standard conditions:

(956,141 acfm)(70 + 460 ^oR/170 + 460 ^oR)(1 - 0.1503) = 683,475 dscfm

Converting to grains/dscf:

(12 lb PM_{10}/hr)(1 hr/60 min)(7000 gr/lb)/(683,475 dscfm) = 0.002 gr/dscf

Converting to 6% O_2 basis:

(0.002 gr/dscf)[(20.95 - 6)/(20.95 – 15.03)] = 0.04 gr/dscf @ 6% O_2

SULFUR DIOXIDE EMISSION FACTORS

Combustion Gas Turbine & Heat Recovery Steam Generator

The SO_2 emission factor is based upon an expected maximum natural gas sulfur content of 0.20 grains per 100 scf and a higher heating value of 1022 BTU/scf.

The sulfur emission factor is calculated as follows:

(0.20 gr S/100 scf)(2 lb SO_2/lb S)(1 lb/7000 gr)(dscf/1022 BTU)(10^6 BTU/MM BTU)

= **0.00056 lb SO_2/MM BTU**

The applicant has calculated and utilized a slightly higher SO_2 emission factor of **0.0006 lb SO_2/MM BTU**.

The corresponding mass SO_2 emission rate at the maximum combined firing rate of 2,124 MM BTU/hr is:

(0.0006 lb SO_2/MM BTU)(2,124 MM BTU/hr) = **1.28 lb SO_2/hr**

The corresponding SO_2 mass emission rate at the maximum gas turbine firing rate of 1,990.5 MM BTU/hr is:

(0.0006 lb SO_2/MM BTU)(1,990.5 MM BTU/hr) = **1.20 lb SO_2/hr**

This is converted to an emission concentration as follows:

(0.0006 lb SO_2/MM BTU)(385.3 dscf/lb-mol)(lb-mol/64.06 lb SO_2)(10^6 BTU/8600 dscf)

= 0.42 ppmvd SO_2 @ 0% O_2

which is equivalent to:

(0.42 ppmvd)(20.95 - 15)/20.95 = 0.12 ppmv SO_2, dry @ 15% O_2

Toxic Air Contaminants

The following toxic air contaminant emission factors were used to calculate worst-case emissions rates used for air pollutant dispersion models that estimate the resulting increased health risk to the maximally exposed population. To ensure that the risk is properly assessed, the emission factors are conservative and may overestimate actual emissions.

Table A-2
TAC Emission Factors[a] for Gas Turbines and HRSG Duct Burners

Contaminant	Emission Factor (lb/MM scf)
Acetaldehyde[c]	6.86E-02
Acrolein	6.43E-03
Ammonia[b]	6.7
Benzene[c]	1.36E-02
1,3-Butadiene[c]	1.27E-04
Ethylbenzene	1.79E-02
Formaldehyde[c]	1.10E-01
Hexane	2.59E-01
Naphthalene	1.66E-03
PAHs[c]	2.32E-03
Propylene	7.70E-01
Propylene Oxide[c]	4.78E-02
Toluene	7.10E-02
Xylene	2.61E-02

[a]California Air Toxics Emission Factors (CATEF) Database as compiled by California Air Resources Board under the Air Toxics Hotspot Program

[b]based upon maximum allowable ammonia slip of 5 ppmv, dry @ 15% O_2 for A-1 and A-2 SCR Systems

[c]carcinogenic compound

In their written comments on the PDOC, EPA Region IX stated that the estimated formaldehyde emissions for the MEC should be revised based upon an emission factor for formaldehyde recently issued in AP-42, Table 3.1-3 “Emission factors for Hazardous Air Pollutants from Natural Gas-Fired Stationary Gas Turbines”, 4/00. Based upon their calculations, the MEC’s total facility formaldehyde emissions would exceed the MACT trigger of 10 tpy if this emission factor were utilized. In addition, intervenors submitted the following comments on the CATEF emission factors utilized to calculate TAC emission rates in the PDOC.

- The acrolein emission factor that was utilized in the PDOC is not accurate since it was based upon source tests conducted in accordance with CARB Method 430 which is no longer endorsed by ARB as an accurate test method for acrolein.

- Emission rates for formaldehyde and benzene are elevated during partial load operation, based upon a study conducted in August 1996 by Carnot Industries for the Electric Power Research Institute (EPRI). The PDOC emission rates do not reflect partial load operation that may occur at the MEC.

It should be noted that this conclusion is based upon the source testing of a GE Frame 7 turbine utilizing steam injection for NO_x control. Because steam injection lowers the flame temperature, elevated emissions of products of incomplete combustion such as CO and formaldehyde are expected. As stated in the abstract for the EPRI study, the load at which a turbine operates can strongly affect emissions of formaldehyde. This effect of load is primarily due to the design and combustion characteristics of a given turbine. Therefore, source testing of a utility-scale gas turbine equipped with DLN combustors operating at partial load is appropriate.

- The CATEF emission factors are based upon turbines equipped with conventional combustors and steam injection for NO_x control. They do not represent the TAC emissions expected from a turbine equipped with dry-low NO_x combustors, as proposed for the MEC.

In response to these comments, the applicant conducted source testing to determine the formaldehyde, acrolein, and acetaldehyde emission rates from a Westinghouse 501F turbine equipped with dry low-NO_x (DLN) combustors during full and partial load operation. EPA Method TO-14 was utilized to test for acrolein in lieu of CARB method 430. The gas turbine that was tested is operated by Calpine in Pasadena, Texas and is not equipped with HRSG duct burners. Table A-3 summarizes the results of the source test and compares them to the CATEF and AP-42 emission factors, where applicable.

Table A-3 TAC Source Test Results

Toxic Air Contaminant	Calculated Emission Factor[a] (lb/MM scf)	CATEF Emission Factor[b] (lb/MM scf)	AP-42 Emission Factor[c] (lb/MM scf)
Full Load Operation, with steam injection power augmentation			
Formaldehyde	<0.165	0.11	0.726
Acrolein	<1.16E-02	6.43E-03	6.54E-03
Acetaldehyde	<7.38E-02	6.86E-02	4.09E-02
Partial Load Operation[d]			
Formaldehyde	0.291	-	-
Acrolein	<0.010	-	-
Acetaldehyde	<5.59E-02	-	-

[a]average of three test runs is shown, except for acrolein numbers, which are based upon one test run

[b]California Air Toxics Emission Factor Database

[c]AP-42, Table 3.1-3 "Emission factors for Hazardous Air Pollutants from Natural Gas-Fired Stationary Gas Turbines", 4/00

[d]approximately 75% load

As shown in Table A-3, the results of the source testing indicate that the CATEF emission factors utilized in the PDOC do not significantly underestimate the formaldehyde, acetaldehyde, or acrolein emissions for a utility-scale gas turbine equipped with DLN combustors. If the highest formaldehyde emission factor of 0.291 lb/MM scf (run 3, partial-load) is utilized, the resulting facility formaldehyde emissions would still be less than the MACT trigger of 10 tons per year and the total increased cancer risk for the facility would still be less than the significance level of 1.0.

Table A-4 TAC Emission Factors for 10-Cell Cooling Tower

Toxic Air Contaminant	Maximum Concentration in Cooling Tower Return Water (ppm)	Emission Factor[a] (lb/hr)
Ammonia	5.5	1.83E-03
Arsenic[b]	0.007	2.33E-06
Cadmium[b]	0.005	1.67E-06
Trivalent chromium[b]	0.003	1.00E-06
Copper	0.021	7.00E-06
Lead[b]	0.055	1.83E-05
Mercury	0.00045	1.50E-07
Nickel	0.0385	1.28E-05
Silver	0.005	1.67E-06
Zinc	0.245	8.17E-05

[a]based upon maximum drift rate of 0.0005% and operation of cooling tower at maximum flow rate of 133,738 gallons per minute; for example:

NH_3 = (5.5/10^6)(0.000005)(133,378 gal/min)(60 min/hr)(8.337 lb/gal)
= 1.83E-03 lb/hr

[b]carcinogenic compound

AMMONIA EMISSION FACTOR

<u>Combustion Gas Turbine & Heat Recovery Steam Generator</u>

Each Gas Turbine/HRSG power train will exhaust through a common stack and be subject to a maximum ammonia exhaust concentration limit of 10 ppmvd @ 15% O_2.

NH_3 emission concentration limit:	5 ppmvd @ 15% O_2
Dry gas flow rate (w/o duct burner):	789,037 dscfm @ 13.44% O_2 by volume
Dry gas flow rate (w/duct burner):	713,457 dscfm @ 12.14% O_2 by volume

Correcting ammonia concentration to actual oxygen content at full load with duct burner firing:

(5 ppmvd)(20.95 – 12.14)/(20.95 – 15) = 7.4 ppmvd @ 12.14% O_2

The ammonia mass emission rate at full load with duct burner firing is therefore:

(7.4 ppmvd/10^6)(713,457 dscfm)(60 min/hr)(lb-mol/385.3 dscf)(17 lb NH_3/lb-mol)

= **14 lb NH_3/hr**

The applicant has calculated and utilized a slightly higher maximum emission rate of **14.22 lb NH_3/hr**.

Based upon the maximum combined heat input for a gas turbine/HRSG of 2,124 MM BTU/hr, this mass emission rate converts to the following emission factor:

(14.22 lb NH_3/hr)/(2,124 MM BTU/hr) = **0.0067 lb NH_3/MM BTU**
= **6.7 lb NH_3/MM scf**

Correcting ammonia concentration to actual oxygen content at full load without duct burner firing:

(5 ppmvd)(20.95 – 13.44)/(20.95 – 15) = 6.31 ppmvd @ 12.14% O_2

The ammonia mass emission rate at full load without duct burner firing is therefore:

(6.31 ppmvd/10^6)(789,037 dscfm)(60 min/hr)(lb-mol/385.3 dscf)(17 lb NH_3/lbmol)

= **13.18 lb NH_3/hr**

Based upon the maximum heat input for a gas turbine of 1,990.5 MM BTU/hr, this mass emission rate converts to the following emission factor:

(13.18 lb NH_3/hr)/(1,990.5 MM BTU/hr) = **0.0066 lb NH_3/MM BTU**
= **6.6 lb NH_3/MM scf**

Table A-5
Regulated Air Pollutant Emission Factors for Fire Pump Diesel Engine

Pollutant	Emission Factor	
	G/bhp-hr	lb/hr
Nitrogen Oxides (as NO_2)	5.89[a]	3.90
Carbon Monoxide	3.55[a]	2.35
Precursor Organic Compounds	0.73[a]	0.48
Particulate Matter (PM_{10})	0.25[a]	0.17
Sulfur Dioxide	0.167	0.11[b]

[a]specifications from manufacturer; Cummins Model 6CTA8.3-F3; 300 hp

[b]based upon maximum expected diesel fuel sulfur content of 0.05% by weight and calculated as follows:

(0.0005 lb S/lb fuel)(15.4 gal/hr)(7.2 lb/gal)(2 lb SO_2/lb S) = 0.11 lb SO_2/hr

Table A-6
Toxic Air Contaminant Emission Factors for Fire Pump Diesel Engine

Toxic Air Contaminant	Emission Factor[a] (lb/MM BTU)
Benzene	9.33E-04
Toluene	4.09E-04
Xylenes	2.85E-04
Propylene	2.58E-03
1,3-Butadiene	3.91E-05
Formaldehyde	1.18E-03
Acetaldehyde	7.67E-04
Acrolein	9.25E-05
Total PAHs	1.68E-04

[a]AP-42 Table 3.3-2, "Speciated Organic Compound Emission Factors for Uncontrolled Diesel Engines"